RECENT INFORMATION TO AID IN DETECTING REGIME SHIFTS IN THE EASTERN TROPICAL PACIFIC OCEAN

S. B. Reilly[1], L.T. Ballance[1], P.C. Fiedler[1], T. Gerrodette[1], R.L. Pitman[1], H.G. Moser[1], L.B. Spear[2], and J.M. Borberg[1]

[1]Southwest Fisheries Science Center
National Marine Fisheries Service, NOAA
8604 La Jolla Shores Drive
La Jolla, California 92037

[2]HT Harvey and Associates

JULY 2002

ADMINISTRATIVE REPORT LJ-02-22

ABSTRACT

We assembled time series of biological and physical measurements resulting from SWFSC field programs in the pelagic eastern tropical Pacific (ETP) and added series of tuna recruitment estimates produced by IATTC, for the period 1975-2000. Each index was normalized and re-presented in terms of standard deviation units to allow appraisal of patterns of change from the long-term mean. Most indices were too sparse to allow interpretation of inter-annual changes, and none began before the now-recognized physical shift in 1976, so that in general the available information does not allow meaningful analysis of whether or not there have been regime-shift-related changes within the ETP biotic provence. Exceptions to the limitation from too-sparse data occur for the tuna recruitment series. Yellowfin tunas appear to have shifted from a low recruitment period to a higher recruitment period following the large El Nino of 1983. Skipjack appear to have undergone a similar shift much later, around 1994. We looked for patterns of coherence in extreme values among indices within each year, and found a modest suggestion of larger anomalies coincident with the El Ninos of 1983, 1987-88, and 1997.

INTRODUCTION

In evaluating the status and trends of exploited populations it is important to consider information on the environment in which the populations exist. This may be viewed by some to be only of academic interest for exploited populations that are recovering as expected, given what is known of their life histories population dynamics. However, it becomes unequivocally relevant to interpreting situations where exploited populations are not recovering. Since the mid-1980s the SWFSC has systematically conducted studies of physical and biological oceanography, and of other large species as part of its monitoring of dolphin stocks in the eastern tropical Pacific (ETP). This body of information, coupled with other data sources from the region, should be considered as part of any thorough assessment of the region's exploited dolphin stocks. The information compiled here includes time series of biological and oceanographic data collected by the field programs of the SWFSC, plus additional unpublished indices for tunas of the region from the Inter-American Tropical Tuna Commission (IATTC). This summary of unpublished, recently-compiled information is intended as a supplement to Fiedler's (2002) comprehensive review of published information relating to environmental change in the eastern tropical Pacific, and Fiedler and Philbrick's (2002) evaluation of oceanographic information collected on SWFSC dolphin cruises during the 1980s and 1990s.

We now must address a question posed by the US Congress as to whether the tuna purse seine fishery is continuing to have a significant adverse impact on previously-depleted dolphin stocks in the ETP, in spite of dramatic reductions in fishery kills. Annual mortality reported from the fishery has been below replacement rates for these stocks since about 1991 (e.g. SWFSC 1999). The research program to address this question is centered around line-transect estimates of absolute abundance, but it also includes projects on the region's ecology, and on possible physiological stress and other fishery-related effects. If our assessments of the abundance, mortality and related data indicate some level of recovery has been occurring, the ecological studies will provide interesting backdrop for improving our understanding of the dynamics of exploited cetaceans. If, however, recoveries are not apparent (given the power of our methods to detect such trends) then it will become important to determine if the environment has changed in ways that could inhibit recovery, or, if the causes are somehow related to fishery activities not directly reflected in the reported annual kills of dolphins in the nets, or, if the environment has changed in ways that could add to or offset effects of fishery activities.

To help address these issues the SWF staff and colleagues have presented seven separate papers of general relevance to the ecology of ETP dolphins (listed in the References). Aware of the need to integrate existing information in some manner, we were impressed with Hare and Mantua's (2000) presentation and analyses, "Empirical evidence for North Pacific regime shifts in 1977 and 1989". They assembled 100 environmental time series (31 climatic, 69 biological), normalized and represented in terms of anomalies from the long-term mean. They conducted two simple forms of analysis to determine that regime shifts had occurred in the North Pacific in 1977 and 1989. The 1989 North Pacific regime shift was not a simple reversal of the 1977 shift. It was more apparent in biological variables than in physical variables. Thus, it could be argued that top-down rather than bottom-up forcing might explain the changes. It was our objective here to determine if sufficient information existed for the ETP to conduct a similar evaluation, and if sufficient information does exist, to determine if empirical evidence of these or other regime shifts exists for the ETP.

An independent scientific peer review of this work was administered by the Center for Independent Experts located at the University of Miami. Responses to reviewer's comments can be found in Appendix A.

METHODS and DATA

We defined the ETP region to include the known distributions of dolphin populations primarily targeted by the tuna purse seine fishery, the northeastern offshore spotted dolphins and eastern spinner dolphins (Dizon et al. 1994). Not coincidentally, these stocks' distributions lie within the core area of the ETP biotic province (McGowan 1974), which also lies generally within the physical boundaries of the ETP warm pool (Fiedler 2002). Thus, our questions regarding regime shifts or decadal-scale changes apply to a well-established, ecologically-defined region and its fauna. The study area for our field programs was designed to cover the known geographical distributions of these dolphin stocks, and given that their distributions are closely representative of the ETP biotic province, our environmental sampling provides reasonable spatial coverage of that ecosystem. As will become quickly apparent, our temporal coverage is far less representative.

Following Hare and Mantua (2000) we established a base time period to cover the longest relevant time series available, the tuna time series, 1975 – 2000 (Maunder 2002a,b, and, Maunder and Harley 2002). We searched for but did not find any other relevant time series of biological indicators for the ETP that covered more than a few years. There are more data series available for the adjacent, but ecologically distinct eastern boundary currents (i.e. the well known sardine and anchovy catch estimates), but we did not include data for species whose ranges are primarily outside of the ETP as defined above. Therefore, the series available for consideration included those from our field programs plus recruitment series for yellowfin, bigeye and skipjack tunas produced by IATTC, and made available in the Commission's stock assessment reports. While these reports have not been formally peer reviewed, we included the recruitment indices from them with the assumption that any biases they might contain do not vary through time. This same assumption of course applies equally to the indices from our field studies.

The following data series are presented here, normalized, with each year's record presented in terms of standard deviation units from the full series zero mean:

- SST, salinity, thermocline depth and wind stress for the "core" area (Fiedler, 2002), Figure 1.
- SST, salinity, thermocline depth and wind stress for the full survey area (Fiedler, 2002), Figure 2.
- Log surface chlorophyll and primary productivity for the core (Figure 3) and full (Figure 4) survey areas (Fiedler and Philbrick, 2002).
- Seventeen larval fish taxa, relative abundance from surface manta tows (Moser et al., 2002), Figure 5.
- Seven fish and cephalopod taxa, relative abundance from night dipnet stations (Pitman et al., 2002), Figure 6.
- Yellowfin tuna, recruitment indices from catch/effort and length-frequency data (Maunder 2002a), Figure 7.
- Skipjack tuna, recruitment indices from catch/effort and length-frequency data (two version, with different model assumptions, from Maunder 2002b), Figure 7.
- Bigeye tuna, recruitment indices from catch/effort and length-frequency data (Maunder and Harley, 2002), Figure 7.
- Nine seabird taxa, relative abundance from sighting surveys (Ballance et al. 2002), Figure 8.
- Four dolphin stocks targeted by the ETP tuna fishery, absolute abundance from line transect surveys (Gerrodette and Forcada, 2001), Figure 9.
- Eight non-targeted cetacean taxa, absolute abundance, from line transect surveys (Gerodette and Forcada, 2002), Figure 10.

We did not use principal components analysis to isolate patterns of common variability in our time series, as Hare and Mantua (2000) did, because our series were too sparse. Most of them consisted of five and three yearly values separated by a gap of seven years, reflecting the sampling coverage of the two major dolphin expeditions, the Monitoring of Porpoise Stocks (MOPS) during 1986-1990, and the Stenella Abundance Research (STAR) cruises of 1988-2000. Smaller numbers of variables were sampled during other years beginning in 1975. During these other years the spatial coverage of cruises was generally less extensive than during the MOPS and STAR cruises.

To detect coordinated changes among the sparse series available, we used a simple analytic approach. We sought to test for coherence among the various data sets in patterns of their anomalies, i.e. to determine if there were years in which many sets coincidentally had extreme values within a year, regardless of the sign of the anomaly. We estimated the proportion of indices with values greater than 1 SD (+ or -), and examined patterns through time of these proportions and their 95% confidence limits.

RESULTS and DISCUSSION

Only the tuna and physical oceanographic time series cover a sufficiently long period to allow appraisal of decadal-scale patterns, and those only for the period since 1976. The other series are simply too thin to justify the types of analyses conducted by Hare and Mantua (2000), and so we have not taken that step. It is apparent from the analyses of Fiedler (2002, and references cited therein) that a shift of some sort occurred in the region during the period 1976-77, as part of an ocean-wide pattern. McPhadden and Zhang (2002) reported a decline in upwelling along the equator since the 1970s, and from this inferred a decline in primary productivity there. As Fiedler (2002) notes, possible effects of this equatorial change on the fauna of the more northerly warm pool are unclear. Fiedler (2002) reported a shoaling of the thermocline in the warm pool area of the ETP in recent decades, and again, whether this is likely to have affected the dolphin populations, and if so whether it caused a negative or positive effect, is uncertain. We have no biological time series for the pelagic eastern tropical Pacific that span the period before and after 1976-77, and so are not able with the information available to determine if there were substantial biological responses to the 1976-77 shift (including the shoaling of the thermocline, assuming those changes are related).

A few observations are suggested from quick visual appraisal of Figures 1 - 10. No decadal shifts or trends are apparent in the oceanographic series[1]. The most complete series, for the tunas, do suggest some decadal-scale changes. Yellowfin appear to have shifted from neagative recruitment anomalies (in terms of the 1976-2000 base period) to positive anomalies after the 1983 El Nino. Bigeye tunas had increased recruitment for about 5 yrs starting around 1989. Skipjack recruitment went from negative anomalies to positive around 1994. As all three types of tunas underwent apparent shifts at substantially different points in time, it would be difficult to assert that these changes were forced by common physical phenomena. Because the tuna recruitment series began at about the same time as the 1976 shift it isn’t possible to determine if that environmental change point affected these populations.

[1]Fiedler (2002) notes: Linear trends of surface temperature in the 1980-2001 time series were not statistically significant, except for post-1997 in the central North Pacific. Linear trends of thermocline depth in the ETP are statistically significant, indicating an overall shoaling of the thermocline of 7.8m in the eastern equatorial Pacific and 6.1m in the ETP warm pool since 1980. However, these trends are very sensitive to the length of the series: trends for 1980-1998, before the moderate La Niña conditions in 1999-2001, are not significant, and trends for 1984-1998 indicate significant deepening of the ETP thermocline. Thus, it is not possible to meaningfully describe linear trends during the 1980-2001 period; ENSO variability predominated.

The information available here does allow us to search for patterns of coherent change among the various physical and biological indices, at least during the limited periods covered. We estimated the proportion of indices measured in each year that exceeded 1.0 SD, and plotted the annual proportions with 95% CLs. (Figure 11). The horizontal dotted line indicates the upper limit of expected values for proportions exceeding one SD unit. Given the overlap among confidence intervals for all years it appears these estimates lack sufficient precision to lead to strong conclusions. However, there is a suggestion that El Nino effects can be seen here. There is an apparent coincidence of the highest three proportions with the three strong ENSO events that occurred during this period (1982-83, 1987-88 and 1997-98).

In conclusion, the data available from our field programs (supplemented by the tuna recruitment estimates produced by IATTC) do not as a whole provide sufficient information to evaluate whether there have been regime shifts or similar decadal changes during the period 1975-2000. Unfortunately, the most pertinent period to examine for such a shift, 1976-77, occurs at the beginning or, or nearly a decade before, the data sets available here. Consequently, we are not able to address whether or not there was any indication of an ecological regime shift within the ETP biotic provence as a result of the 1976-77 physical changes noted by Fiedler (2002 and references therein). In the nearly-complete tuna series there is some suggestion of shifts during the period since 1977 for all three species, but the shift points do not coincide with each other, and only the yellowfin tuna shift is clearly coincident with a notable physical event. There is a suggestion of ENSO effects in patterns of the anomalies that bears further scrutiny.

LITERATURE CITED

Anonymous. 1999. Report to Congress on the initial finding, required under the Marine Mammal Protection Act of 1972 as amended by the International Dolphin Conservation Program Act of 1997. Prepared by the Southwest Fisheries Science Center, National Marine Fisheries Service, 25 March 1000. 54pp. [Available from: http://swfsc.nmfs.noaa.gov/prd/congress/congress.htm]

Ballance, L.T., R.L. Pitman, L. B. Spear, P. C. Fiedler (2002). Investigations into temporal patterns in distribution, abundance and habitat relationships within seabird communities of the eastern tropical Pacific. Administrative Report No. LJ-02-17, NMFS, Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, CA 92037.

Dizon, A.E., W.F. Perrin and P.A. Akin. (1994). Stocks of dolphins (*Stenella* spp. and *Delphinus delphis*) in the eastern tropical Pacific: a phylogeographic classification. NOAA Technical Report NMFS 119: 1-20.

Fiedler, P.C. and V. Philbrick (2002). Environmental change in the eastern tropical Pacific Ocean: Observation in 1986-1990 and 1998-2000. Administrative Report No. LJ-02-15, NMFS, Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, CA 92037.

Fiedler, P.C. (2002). Environmental change in the eastern tropical Pacific Ocean: Review of ENSO and decadal variability. Administrative Report No. LJ-02-16, NMFS, Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, CA 92037.

Gerrodette, T. and J. Forcada. (2002). Estimates of abundance of northeastern offshore spotted, coastal spotted, and eastern spinner dolphins in the eastern tropical Pacific Ocean. Administrative Report No. LJ-02-06, NMFS, Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, CA 92037.

Gerrodette, T. and J. Forcada (2002). Estimates of abundance of striped and common dolphins, and pilot, sperm and bryde's whales in the eastern tropical Pacific Ocean. Administrative Report No. LJ-02-20, NMFS, Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, CA 92037.

Hare, S.R. and N.J. Mantua (2000). Empirical evidence for North Pacific regime shifts in 1977 and 1989. Progress in Oceanography 47: 103-145.

Maunder, M. (2002a). Status of yellowfin tuna in the eastern Pacific Ocean in 2001, and outlook for 2002. Inter-American Tropical Tuna Commission, Background Paper A2 for the 69th Meeting of the IATTC (supplement to IATTC Stock Assessment Report 2).

Maunder, M. (2002b). Status of skipjack tuna in the eastern Pacific Ocean in 2001, and outlook for 2002. Inter-American Tropical Tuna Commission, Background Paper A3 for the 69th Meeting of the IATTC (supplement to IATTC Stock Assessment Report 2).

Maunder, M. and S. Harley (2002). Status of bigeye tuna in the eastern Pacific Ocean in 2001, and outlook for 2002. Inter-American Tropical Tuna Commission, Background Paper A4 for the 69th Meeting of the IATTC (supplement to IATTC Stock Assessment Report 2).

McGowan, J. A. (1974). The nature of oceanic ecosystems. Pp. 9-28 in: C.B. Miller (ed.), The Biology of the Oceanic Pacific. Oregon State Univ. Press, Corvallis.

Moser, H. G., P. E. Smith, R.L. Charter, D.A. Ambrose, W. Watson, S.R. Charter and E.M Sandknop (2002). Preliminary report on ichthyoplankton collected in manta (surface) net tows on marine mammal surveys in the eastern tropical Pacific: 1987-2000. Administrative Report No. LJ-02-18, NMFS, Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, CA 92037.

Pitman, R.L., L.T. Ballance, and P.C. Fiedler (2002). Temporal patterns in distribution and habitat associations of prey fishes and squids. Administrative Report No. LJ-02-19, NMFS, Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, CA 92037.

Reilly, S.B., P.C. Fiedler, T. Gerrodette, L.T. Balance, R.L. Pitman, J.M. Borberg and R. Holland. (2002). Eastern tropical Pacific dolphin habitats- Interannual variability 1986-2000. Administrative Report No. LJ-02-21, NMFS, Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, CA 92037.

Watters, G. and M. Maunder (2001). Status of bigeye tuna in the eastern Pacific Ocean. Inter-American Tropical Tuna Commission, Stock Assessment Report. 1: 109-210.

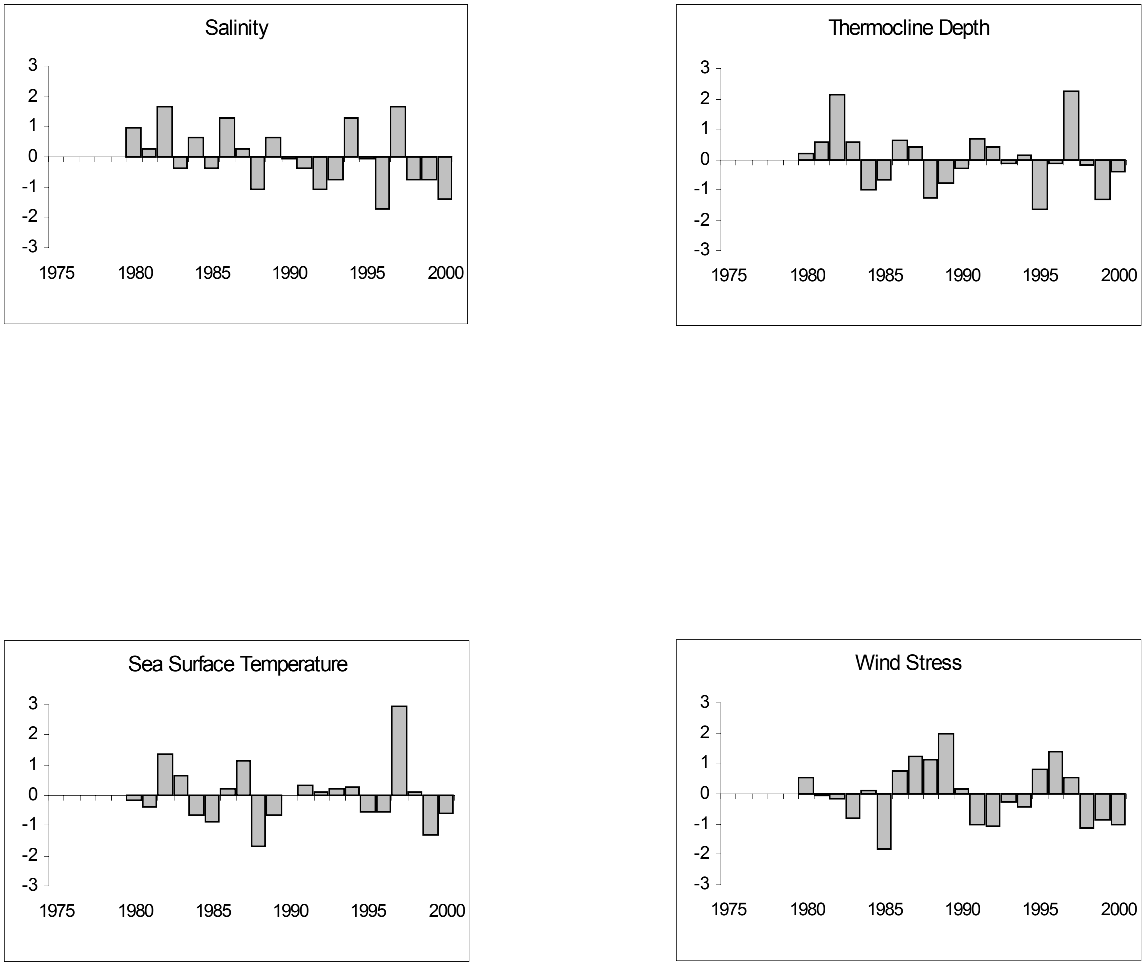


Figure 1. Physical oceanographic data for survey area, from Fiedler (2002)

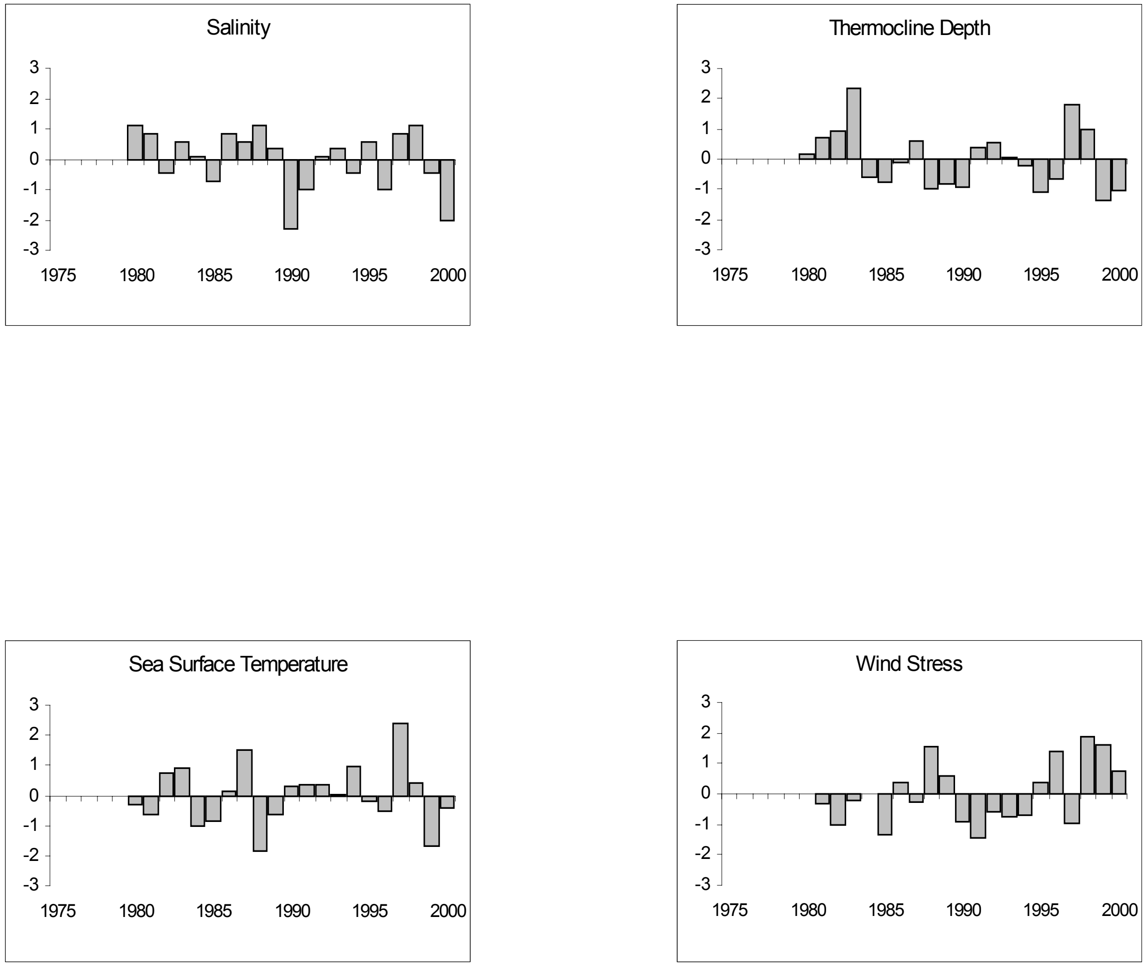
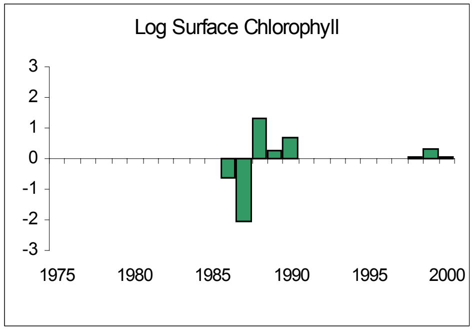


Figure 2. Physical oceanographic data for core area, from Fiedler (2002).



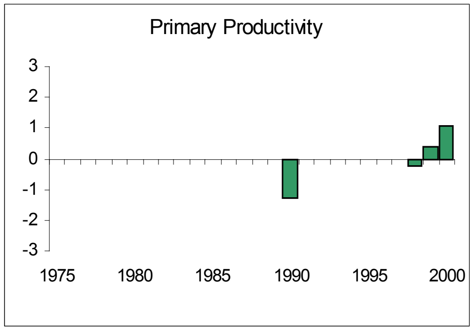
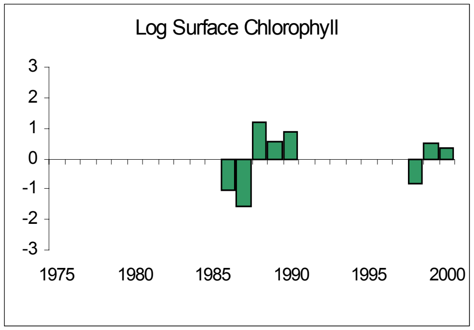


Figure 3. Biological oceanographic data for survey area, from Fiedler and Philbrick (2002).



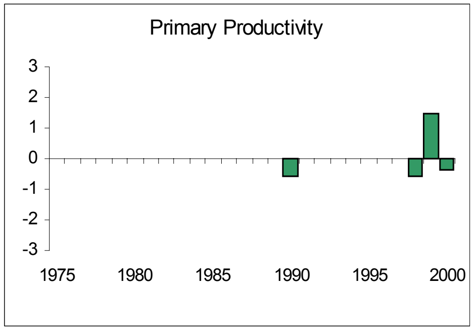


Figure 4. Biological oceanographic data for core area, from Fiedler and Philbrick (2002).

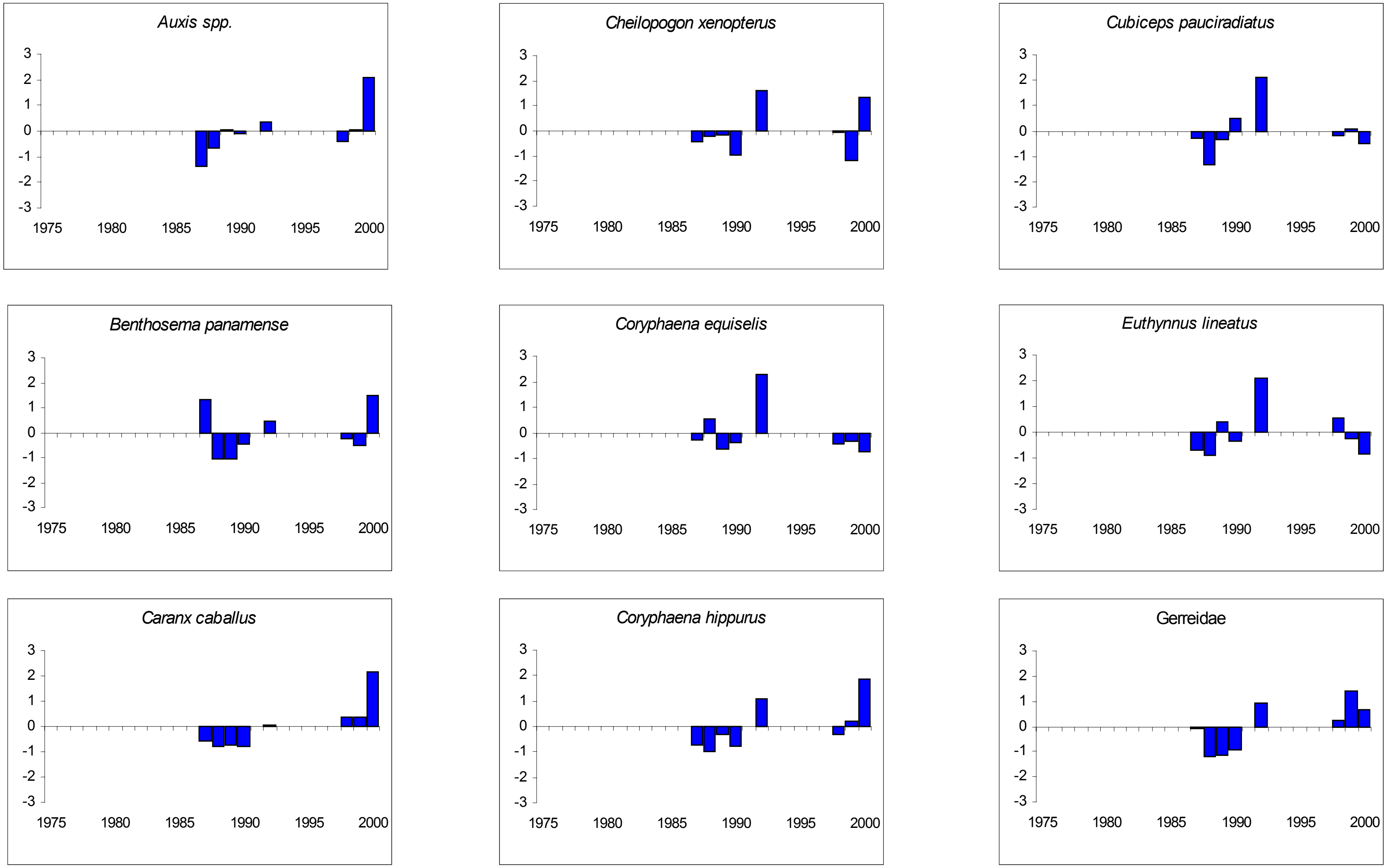


Figure 5. Larval fish, from Moser et al. (2002).

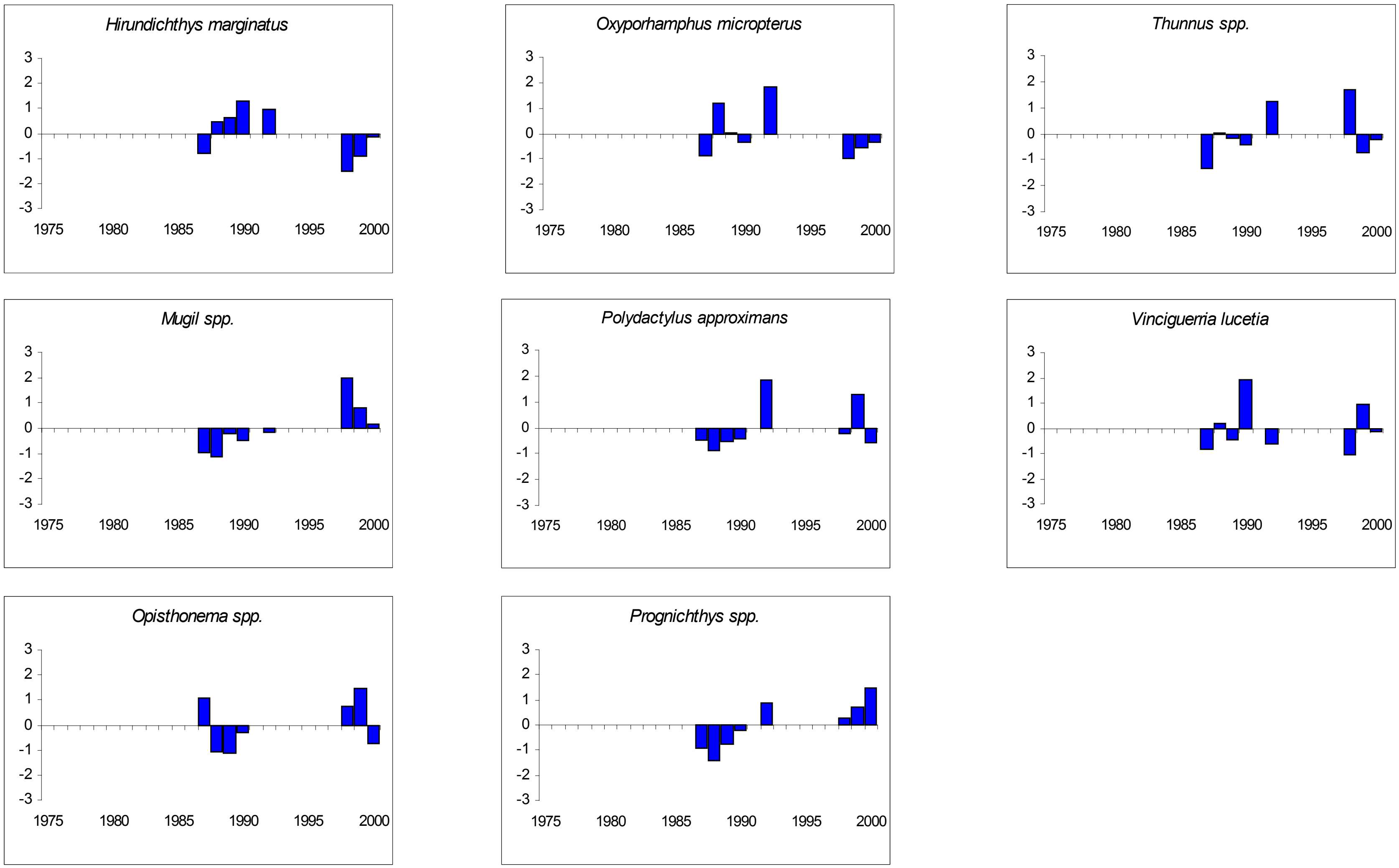


Figure 5. (continued)

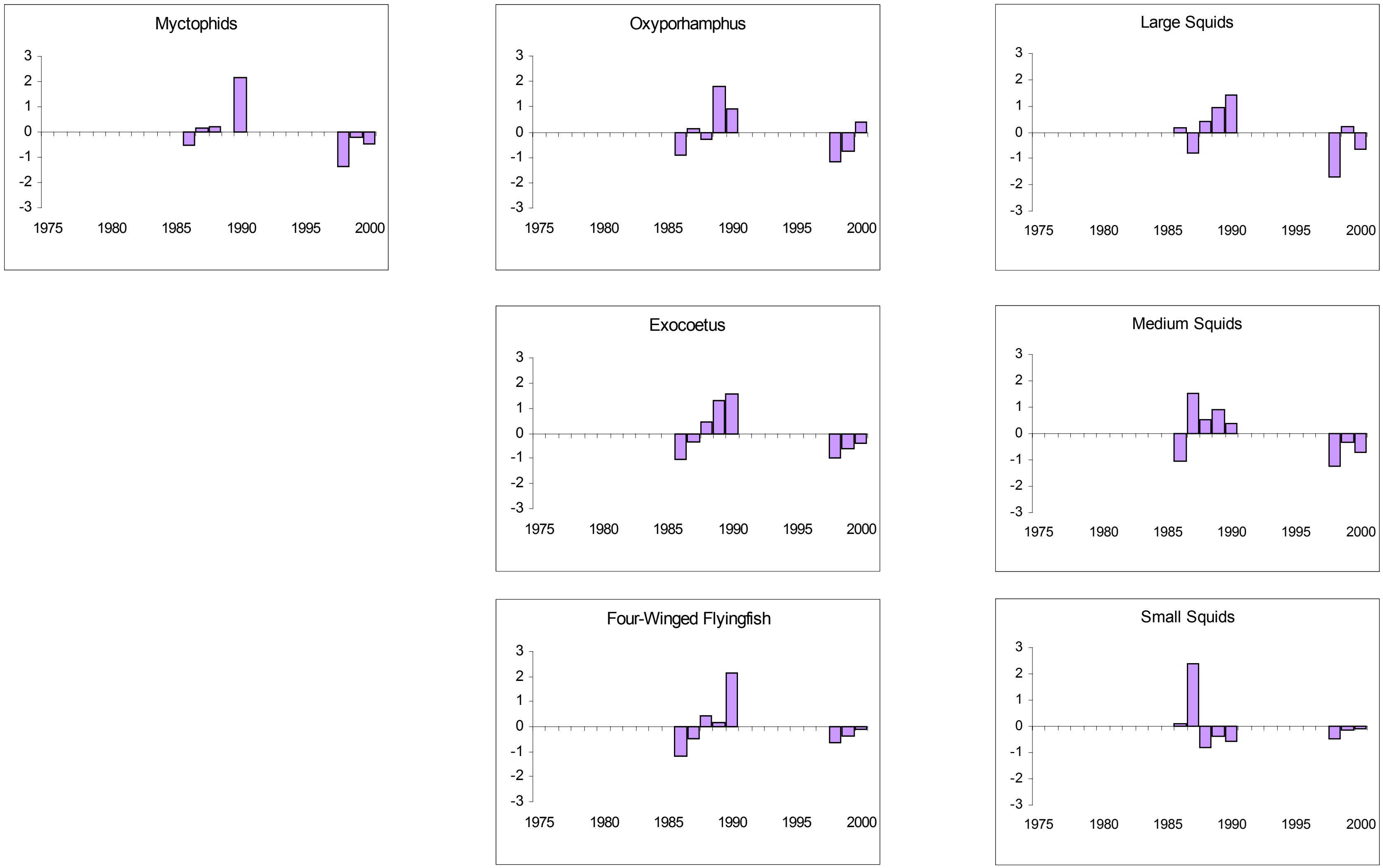


Figure 6. Fish and cephalopods from dipnet stations (Pitman et al., 2002).

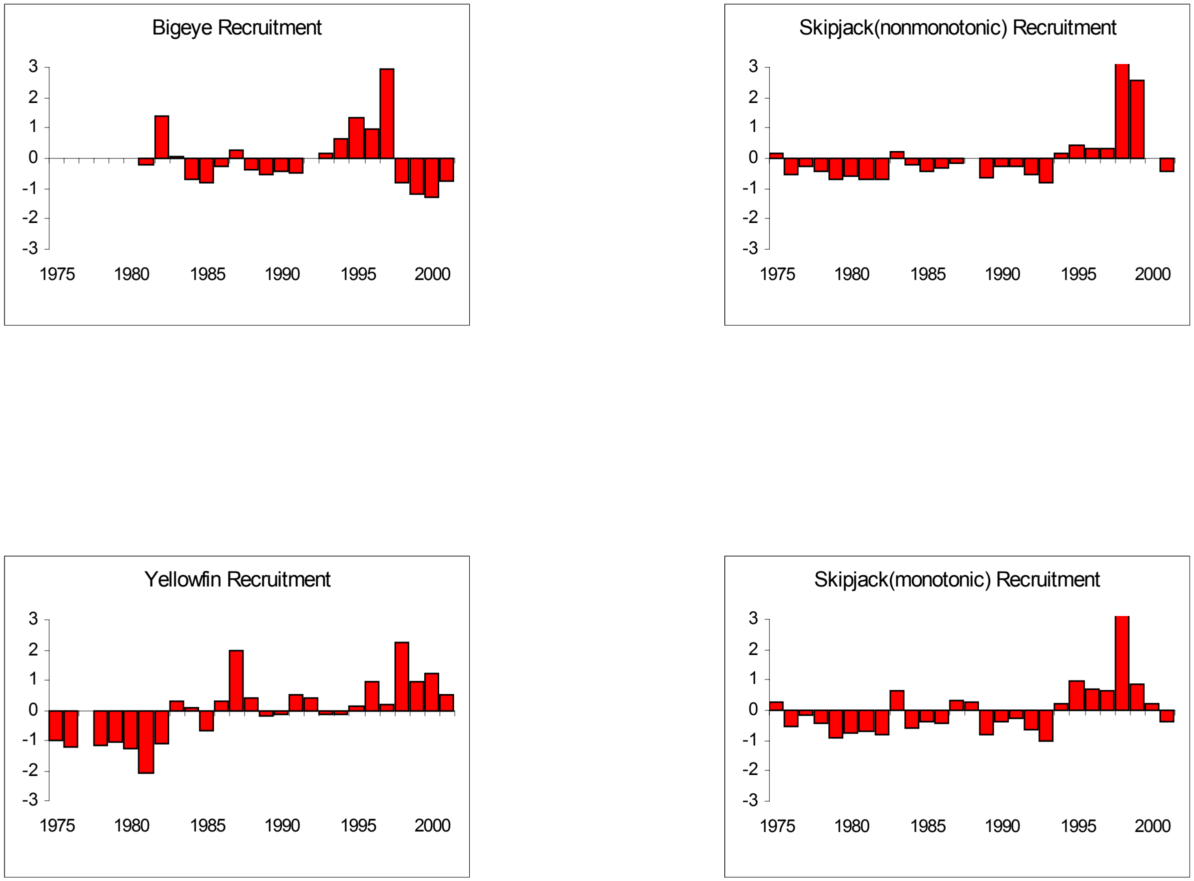


Figure 7. Bigeye, yellowfin and skipjack tuna recruitment, from Maunder (2002a), Maunder and Harley (2002) and Maunder (2002b).

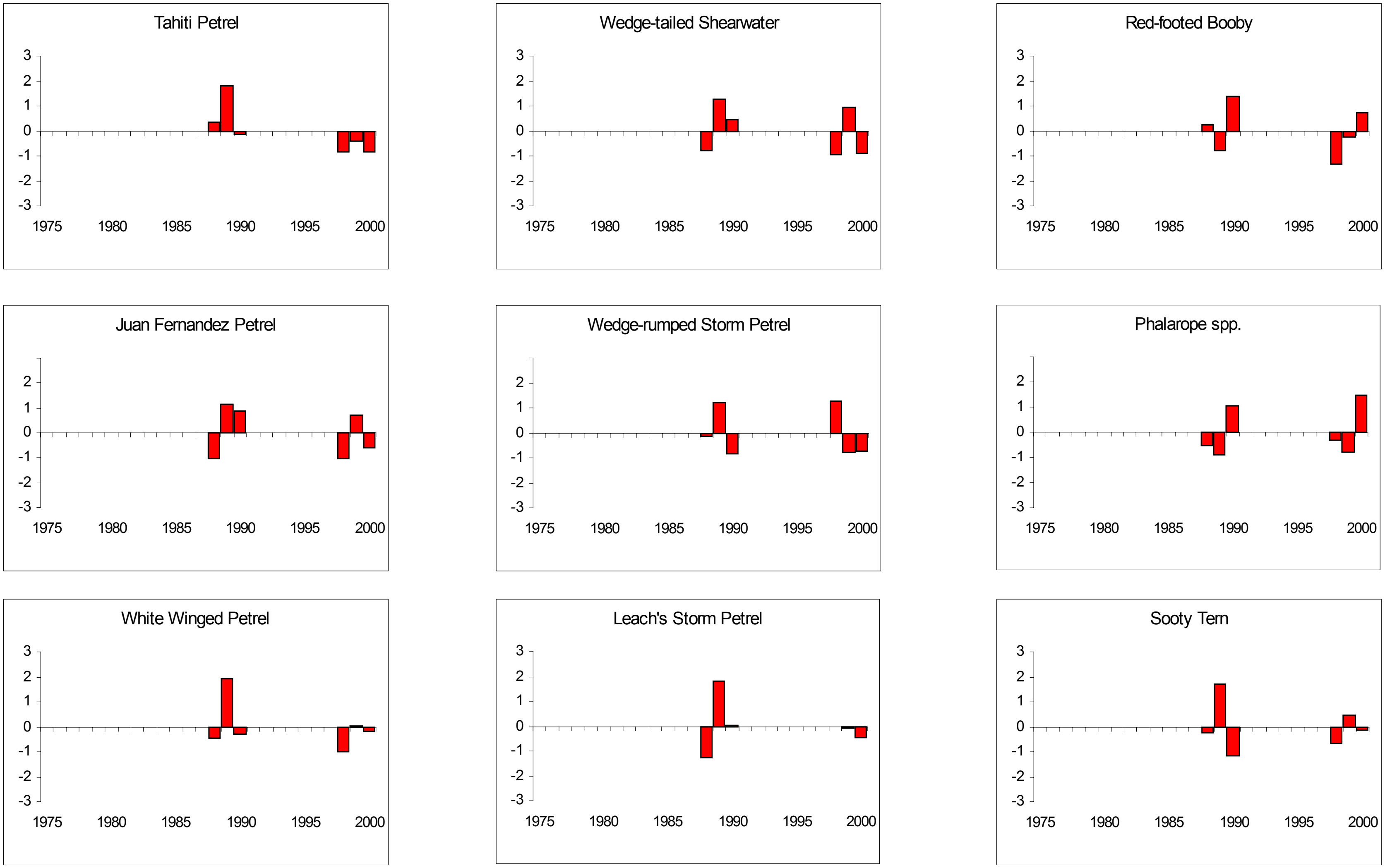


Figure 8. Seabirds, from Ballance et al. (2002).

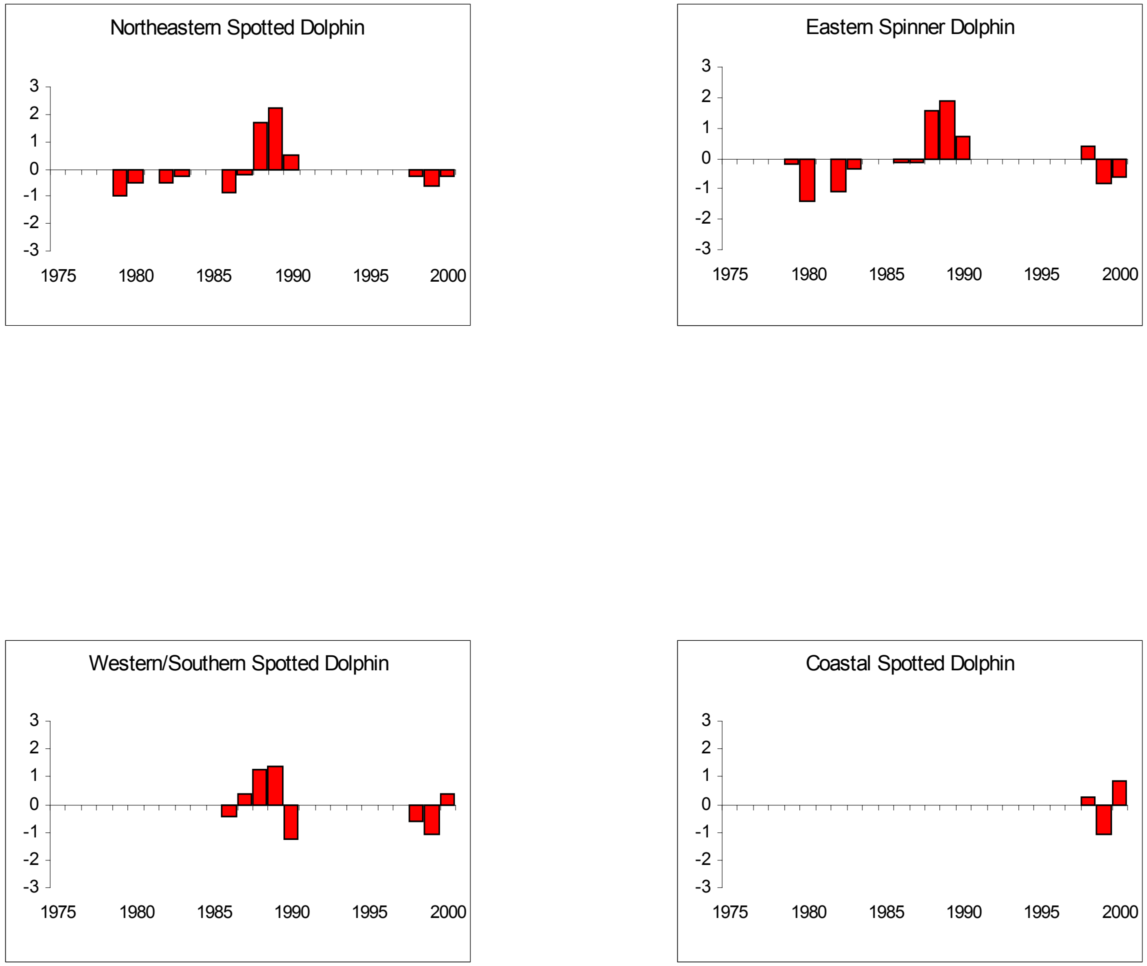


Figure 9. Cetacean target species, from Gerrodette & Forcada (2001).

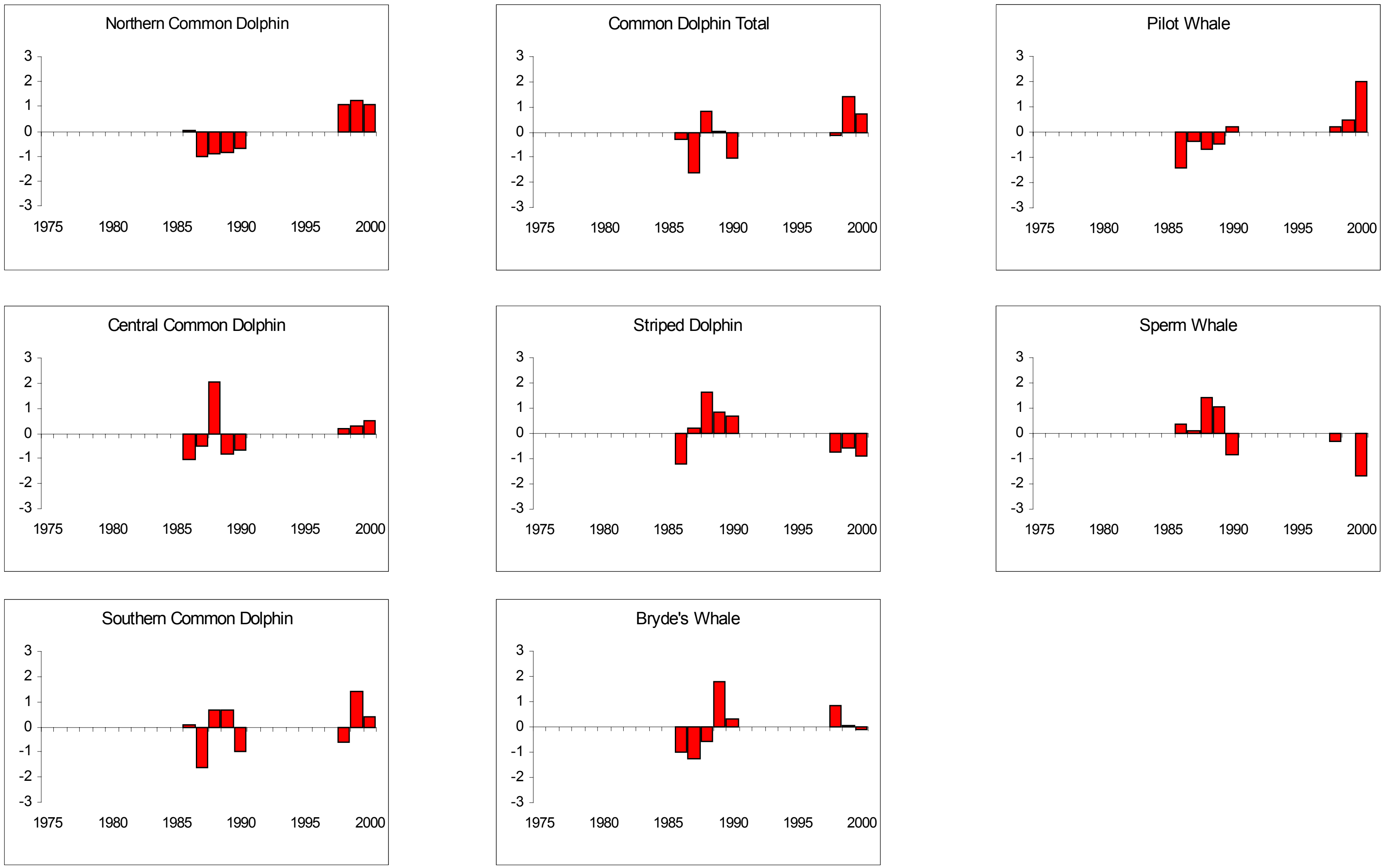


Figure 10. Cetacean non-target species, from Gerrodette and Forcada (2002).

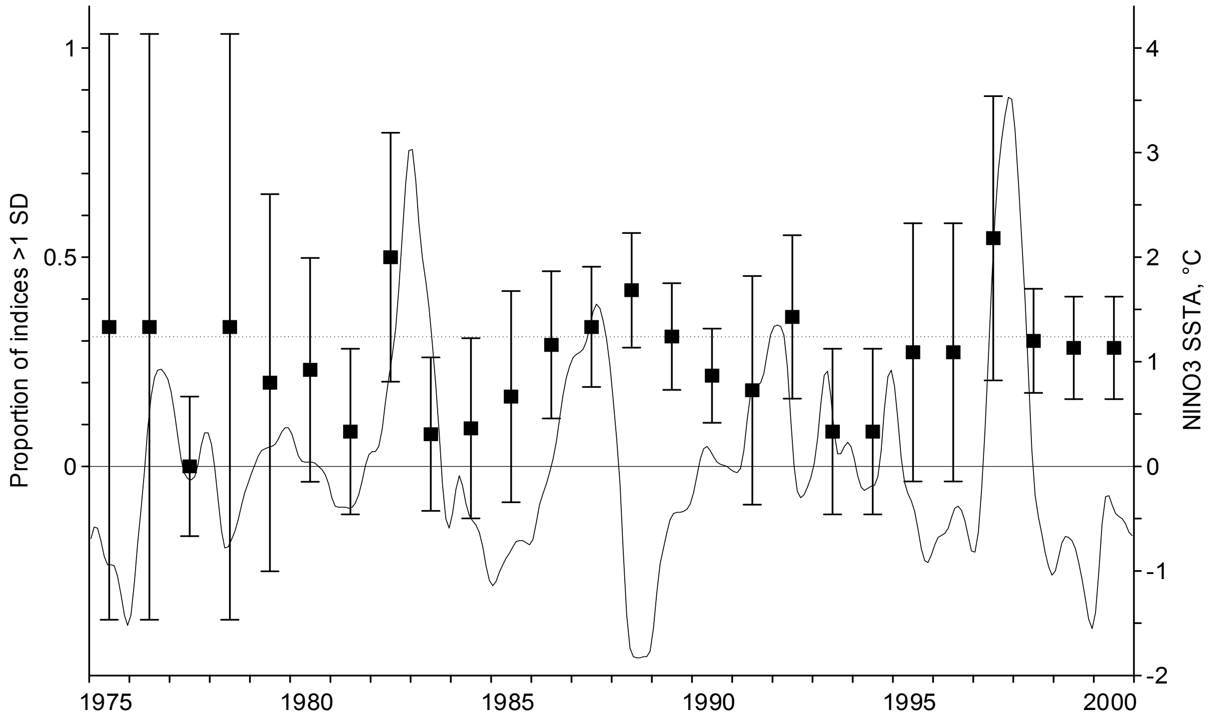


Figure 11. The proportions of all available indices that had values greater than 1 standard deviation unit (positive or negative) per year, for the years 1975 – 2000. Bars indicate 95% confidence limits. The horizontal dotted line shows expected limit for one standard deviation. Continuous line is the NINO3 ocean/climate index.

APPENDIX

Responses to comments by CIE reviewers

Dower

The authors should explore whether the application of distribution-free statistical methods might offer a way to better deal with some of the admittedly sparse data series.

Response: Done. We did explore available distribution-free statistics, and found that the simple patterns in proportions of available statistics that were greater than one SD was the best approximation to the intent of this recommendation.

Drinkwater

Non-parametric statistics, such as rank correlations, should be used to examine the possibility of trends. This would include the statistical probability of obtaining the observed number showing a positive (or negative) trend out of the total number of indices available

Response: Done. See response above, and revised draft.

For the biological data, the focus of the papers was addressing possible changes in abundance. However, changes in growth, size-frequency, species composition (where appropriate) and recruitment are all as important as abundance. These should be explored where the data allow.

Response: Thanks, good suggestion, and we plan to pursue this in the near future. There wasn’t sufficient time to do so for this revision.